Timber Management Guidelines for the Protection of Fish Habitat

April, 1988
Fisheries Branch

Ontario
Ministry of
Natural
Resources

© 1988, Queen's Printer for Ontario

Printed in Ontario, Canada

Single copies of this publication are available for $4.00 from the addresses noted below.

Current publications of the Ontario Ministry of Natural Resources, and price lists, are obtainable through the Ministry of Natural Resources Public Information Centre, Room 1640, Whitney Block, 99 Wellesley Street West, Toronto, Ontario M7A 1W3 (personal shopping and mail orders).

And:

Personal shopping: Ontario Government Bookstore, Main Floor, 880 Bay Street, Toronto.

Mail Orders: MGS Publications Services Section, 5th Floor, 880 Bay Street, Toronto, Ontario M7A 1N8. Telephone 965-6015. Toll free long distance 1-800 268-7540, in Area Code 807 dial 0-Zenith 67200.

Cheques or money orders should be made payable to the Treasurer of Ontario, and payment must accompany order.

Preface

The guidelines presented here are designed to assist in the protection of fish habitat during the planning and implementation of timber management operations. The guidelines were developed on a biological basis for the purpose of protecting fish habitat and water quality. In conjunction with related guidelines for other resource values (e.g. tourism, moose habitat), they represent Ministry of Natural Resources policy which protects such values while permitting acceptable timber management operations to take place.

The present guidelines are intended to protect aquatic ecosystems which support fish populations whose maintenance is necessary to the achievement of stated fisheries management objectives. Within an ecosystem some fish habitats are of critical importance to the maintenance of a population and the ecosystem itself. These habitats (e.g. spawning areas) support essential functions and are usually limited in availability. Such habitats are given a particularly high degree of protection.

The guidelines are designed to maintain water quality at a level sufficient to protect aquatic ecosystems. As the maintenance of aquatic life is usually the most sensitive use of a waterbody, it is anticipated that use of the guidelines will generally also minimize impairment of water quality.

The guidelines are based on the need to protect fish habitat from the potentially harmful effects of certain major timber management operations. These operations are the construction of access roads, location of landings, harvesting, and mechanical site preparation. The guidelines indicate how these operations should be restricted or modified in shoreland areas to protect specific fish habitats.

The guidelines are intended to provide a consistent approach to the protection of fish habitat across Ontario. Because of the many site-specific factors affecting requirements for protection, the guidelines should be used with some flexibility. However, any departures from the guidelines must be consistent with the objective of protecting fish habitat.

In some cases, adherence to the guidelines may impose severe constraints on timber management. For example, restrictions on road locations near lakes and streams could prevent any timber management operations from occurring within a large area. Where no reasonable alternatives exist, exceptions to the guidelines may be considered provided it can be demonstrated that operations can be carried out so as to ensure protection of fish habitat.

Users of the guidelines should refer to the Background portion of this document for assistance. The Background indicates how the guidelines should be used within the context of the Ministry's timber management planning process. The Background also describes the potential effects of timber management operations on fish habitat, defines a number of terms, and presents a rationale for maintaining habitat values by use of the guidelines.

Acknowledgements

These guidelines were prepared with the collaboration of many people. The primary author was John T. Allin of Fisheries Branch. Numerous staff of the Ministry of Natural Resources provided advice and assistance during the developmental phase. In particular, Chris Brousseau, Doug Dodge, Art Holder and Neville Ward contributed many useful ideas and suggestions.

The guidelines received extensive review both within the Ministry of Natural Resources and within other organizations. All parties who had any involvement in the Class Environmental Assessment for Timber Management were given the opportunity to review draft guidelines. Representatives of other provincial ministries, the tourism and timber industries, and other interest groups provided comments. Their helpful advice and suggestions are gratefully acknowledged.

TABLE OF CONTENTS

		Page
GUIDELINES		1
BACKGROUND		4
1.0	**Introduction**	4
1.1	Purpose	4
2.0	**Responsibility to Protect Fish Habitat**	4
3.0	**Habitat Requirements of Fish**	4
4.0	**Potential Effects of Timber Management Operations on Fish Habitat**	5
4.1	Water Yield	5
4.2	Erosion and Sedimentation	6
4.2.1	Erosion	6
4.2.2	Sedimentation	6
4.3	Logging Debris	6
4.4	Nutrient Input	7
4.5	Food Production	7
4.6	Cover	7
4.7	Temperature	7
5.0	**Factors Influencing the Requirements for Modified Timber Management**	8
5.1	Location of Areas of Operation	8
5.2	Habitat Protection Requirements	8
5.2.1	Critical Fish Habitats	8
5.2.2	Lake Trout Lakes, Self-Sustaining Brook Trout Lakes, Aurora Trout Lakes	8
5.2.3	Other Fish Habitats	8
5.3	Composition of Shoreland Vegetation	9
5.4	Width of Shoreland Vegetation	9
5.5	Continuity of Standing Timber	10
5.6	Blowdown	10
6.0	**Areas of Concern**	10
6.1	Identification of Areas of Concern	10
6.2	Size of Areas of Concern	10
7.0	**Rationale for Provincial Guidelines**	11
7.1	Introduction	11
7.2	Width of Areas of Concern	11
7.3	Operations within Areas of Concern	11
7.3.1	Roads	11
7.3.2	Landings	11
7.3.3	Harvesting	11
7.3.4	Mechanical Site Preparation	12
7.4	Definitions	12
REFERENCES		13

GUIDELINES

1. Shorelands which have been selected for timber management operations and which are adjacent to fish habitats requiring protection should be identified as areas of concern.

2. In general, the following guide to determining the width of areas of concern should be used:

Slope (%)	Slope Angle (°)	Width of Area of Concern
0 – 15	0 – 8	30 m
16 – 30	9 – 17	50 m
31 – 45	18 – 24	70 m
46 – 60	25 – 31	90 m

Areas of concern should be measured from the high water mark. The widths specified apply to each side of a stream.

The above widths of areas of concern are for general use. Where better information is available on a local basis, the widths may be modified in a manner consistent with the protection of fish habitat.

Where standing timber is to be maintained for the protection of fish habitat, the width of areas of concern may have to be greater than specified above in order to protect the stand from blowdown.

3. Where timber management operations cannot be carried out in an area of concern so as to ensure protection of fish habitat, the area of concern should be designated as a reserve. No operations will then be carried out in that area.

4. Where timber management operations can be modified so as to ensure protection of fish habitat, appropriate modified management prescriptions should be developed.

5. Modifications to timber management operations required to protect specific fish habitats are as follows:

5.1 Lake Trout Lakes, Self-Sustaining Brook Trout Lakes, Aurora Trout Lakes

5.1.1 Roads should not be constructed within areas of concern.

5.1.2 Landings should not be located within areas of concern.

5.1.3 Harvesting within areas of concern should be severely restricted. Possible options are:
(a) no harvesting;
(b) selection cutting (removal of individual trees or small groups of trees), where it can be demonstrated that fish habitat will be protected. In particular, any harvesting must be carried out so as to avoid damaging banks, keep logging debris away from the shoreline, and avoid the occurrence of significant erosion. Use of light equipment and harvesting when soils are frozen will reduce the risk of erosion. No further harvesting should occur until the areas originally cut have become stabilized through revegetation.

5.1.4 Mechanical site preparation should not be carried out within areas of concern.

5.2 Other Lakes

5.2.1 Roads should not be constructed within areas of concern. Exceptions may be considered where it can be demonstrated that fish habitat will be protected. However, roads should not be located in areas adjacent to critical fish habitats (headwater areas, spawning and nursery areas, wetlands).

5.2.2 Landings should not be located within areas of concern.

5.2.3 Harvesting within areas of concern should be limited, and restricted to situations where it can be demonstrated that fish habitat will be protected. Any harvesting should be carried out so as to avoid damaging banks, keep logging debris away from the shoreline, and avoid the occurrence of significant erosion. No further harvesting should occur until the areas originally cut have become stabilized through revegetation. Possible options are:
(a) no harvesting;
(b) selection cutting;
(c) shelterwood cutting or limited clear cutting (e.g. strip or block clear cuts). No more than 50% of the shoreline should be cut by these methods and any clear cutting should occur, where feasible, in non-contiguous blocks or strips. Such cutting should not be carried out in areas adjacent to critical fish habitats or between the lake and nearby roads.

5.2.4 Mechanical site preparation should be restricted to situations where it can be demonstrated that fish habitat will be protected. Exposure of mineral soil should be minimized and furrows should be oriented at right angles to the slope.

5.3 Coldwater Streams

Coldwater streams include tributaries to coldwater lakes which are not inhabited by salmonid fish species but which are critical sources of water to these lakes.

5.3.1 Roads should not be constructed within areas of concern except where necessary to cross the stream.

5.3.2 Landings should not be located within areas of concern.

5.3.3 Harvesting within areas of concern should be severely restricted. Possible options include:
(a) no harvesting;
(b) selection cutting, where it can be demonstrated that fish habitat will be protected. Any harvesting should be carried out so as to avoid damaging banks, keep logging debris away from the stream, and avoid the occurrence of significant erosion. Shade should be maintained on both sides of the stream and throughout its length. No further harvesting should occur until the areas originally cut have become stabilized through revegetation.

5.3.4 Mechanical site preparation should not be carried out within areas of concern.

5.4 Coolwater and Warmwater Streams

5.4.1 Roads should not be constructed within areas of concern except where necessary to cross the stream. Other exceptions may be considered where it can be demonstrated that fish habitat will be protected. However, roads should not be located in areas adjacent to critical fish habitats.

5.4.2 Landings should not be located within areas of concern.

5.4.3 Harvesting within areas of concern should be limited, and restricted to situations where it can be demonstrated that fish habitat will be protected. Any harvesting should be carried out so as to avoid damaging banks, keep logging debris away from the stream, and avoid the occurrence of significant erosion. No further harvesting should occur until the areas originally cut have become stabilized through revegetation. Possible options are:
(a) no harvesting;
(b) selection cutting;
(c) shelterwood cutting or limited clear cutting (e.g. strip or block clear cuts). No more than 50% of the length of streams should be cut by these methods and any clear cutting should occur, where feasible, in noncontiguous blocks or strips. Such cutting should not be carried out in areas adjacent to critical fish habitats or in areas upstream of such habitats as far as the first permanent water basin or bog. Also, such cutting should not occur between the stream and nearby roads.

5.4.4 Mechanical site preparation should be restricted to situations where it can be demonstrated that fish habitat will be protected. Exposure of mineral soil should be minimized and furrows should be oriented at right angles to the slope.

The guidelines are summarized in Table 1.

TABLE 1

TIMBER MANAGEMENT GUIDELINES FOR THE PROTECTION OF FISH HABITAT - A SUMMARY -

FISH HABITAT	SLOPE	WIDTH OF AREA OF CONCERN*	MODIFICATIONS TO TIMBER MANAGEMENT OPERATIONS WITHIN AREAS OF CONCERN			
			Roads	Landings	Harvesting Options	Mechanical Site Preparation
1. Lake Trout Lakes, Self-Sustaining Brook Trout Lakes, Aurora Trout Lakes	0 - 15% 16 - 30% 31 - 45% 46 - 60%	30m 50m 70m 90m	No	No	• No harvesting • Selection cutting on a restricted basis; avoid damaging banks, keep debris away, avoid occurrence of erosion	No
2. Other Lakes	As above	As above	No	No	• No harvesting • Selection cutting on a restricted oasis • Shelterwood or limited clear cutting; do not cut near critical fish habitats or roads	Restricted; minimize exposure of mineral soil, orient furrows at right angles to slope
3. Coldwater Streams	As above	As above	Stream crossings only	No	Same as for #1, Lake Trout Lakes; maintain shade on both sides	No
4. Coolwater and Warmwater Streams	As above	As above	Stream crossings only	No	Same as for #2, Other Lakes; no shelterwood or clear cutting upstream of critical fish habitats	Same as for #2, Other Lakes

* Width may have to be greater to reduce the risk of blowdown.

BACKGROUND

1.0 Introduction

In many parts of Ontario merchantable timber occurs in areas adjacent to aquatic environments (shoreland areas). Many of these aquatic environments, including wetlands, lakes and streams, provide or can potentially provide valuable habitat for fish.

Little information is available as to the impact of timber management operations on fish habitat in Ontario. Studies elsewhere demonstrate a number of potentially harmful effects. Both the quantity and quality of fish habitat may be reduced. Consequently, the protection of fish habitat may necessitate restricting the location of timber management operations or modifying these operations in certain ways.

The need to restrict or modify timber management operations in order to protect resources such as fish habitat is recognized in the Ministry's Policy for the Integration of Other Resource Values in Timber Management (1985). The policy outlines a planning process for determining whether requirements for the protection of other values would permit timber management operations to occur in specific areas, and, if so, whether such operations must be modified.

Implementation of the policy requires the identification of areas in which other resource values exist. Fish habitats are normally identified through the Ministry's Aquatic Habitat Inventory Survey Program, and may be further characterized through assessment studies. It is imperative that planning of habitat inventory programs be closely coordinated with timber management planning in order to provide the requisite habitat information when it is needed for decision-making.

Recognition of fish habitat values early in the timber management planning process can assist in establishing the general direction for the twenty-year period of the timber management plan. However, fish habitat information is used most extensively during the preparation of the five-year plan of operations when decisions concerning operations in specific areas are made.

1.1 Purpose

The purpose of this document is to assist decision-makers in the use of the Timber Management Guidelines for the Protection of Fish Habitat in the planning and implementation of timber management operations. Habitat requirements of fish and potential effects of timber management operations on fish habitat are described, and a rationale is presented for maintaining habitat values by use of the guidelines.

The guidelines are intended to provide a consistent approach to the protection of fish habitat across Ontario. Because of the wide range of forest types, site conditions, climatic factors and fish habitats in the province, the guidelines should be used with some flexibility and should be adapted to local conditions.

2.0 Responsibility to Protect Fish Habitat

The obligation to protect fish habitat in Ontario derives from a number of goals and objectives of the Ministry of Natural Resources.

The goal of the Ministry is "to provide opportunities for continuous economic and social benefits to the people of Ontario through the development and conservation of Ontario's natural resources".

The objective of the Outdoor Recreation Group includes the provision of "a variety of outdoor recreation opportunities accessible to and for the continuous benefit of the people of Ontario".

One goal identified in the first Strategic Planning for Ontario Fisheries report is "protection of fish communities and fisheries habitat to ensure man of continued supplies of fish and fishing opportunities ..." (SPOF, 1976).

The attainment of these goals and objectives requires the effective protection of fish habitat to ensure perpetuation of the fisheries resource and the benefits it provides.

Legislative authority to protect fish habitat is contained in the **Fisheries Act** (Canada). This federal act is administered in Ontario by the Ministry of Natural Resources. Section 31 prohibits "... any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat". The Act also binds the Crown (Section 71).

In 1982 the Cabinet Committee on Resources Development established the **Fisheries Act** (Canada) as the main legislative tool for the protection of fish habitat in Ontario. The Ministry of Natural Resources is the lead ministry in administering this policy.

Responsibility for decisions as to habitat protection requirements in a given situation rests with the local manager. In the case of timber management planning this responsibility is shared between the Regional Director and the District Manager, who approve operational prescriptions contained in the five-year plan of operations.

3.0 Habitat Requirements of Fish

The habitat requirements of fish are complex, and a detailed discussion is beyond the scope of this document. Only features of general importance and of relevance to the impacts of timber management are addressed.

In simplest terms, fish require habitat in which they can complete their life cycle and reproduce. The habitat required varies among species and among stages in the life cycle of each species. As a result, habitat requirements vary both in time and space, necessitating good knowledge of local fish resources if these requirements are to be recognized and provided.

Some habitats are of critical importance to fish populations because of the essential functions they support. Such "critical fish habitats" are defined here as habitats required for the maintenance of a healthy fish population of importance to achieving stated fisheries management objectives. The availability of such habitats is usually limited and they are often very sensitive to environmental change. Hence they require a particularly high degree of protection. Critical fish habitats include the following:

(a) headwater areas (e.g. springs) – the source of water to downstream areas, and often important for spawning;

(b) spawning areas – essential for reproduction and frequently limited in availability;

(c) nursery areas – provide cover and food for young fish;

(d) wetlands – stabilize water flow and frequently provide spawning or nursery habitat;

(e) migration areas – provide access to spawning, nursery and other habitats.

Because fish species vary in their habitat requirements, they also vary in their sensitivity to the effects of timber management operations. In general, coldwater species (e.g. lake trout) are somewhat more sensitive than other species for the following reasons:

(a) coldwater species are less tolerant of high temperatures and large diurnal fluctuations in temperature, thus are sensitive to removal of shade;

(b) coldwater species have more stringent requirements for dissolved oxygen; lake trout are particularly sensitive to the effects of reduced oxygen levels resulting from nutrient input since they are confined to the deep, cool basins of thermally stratified lakes;

(c) most coldwater species spawn in gravel; their eggs and developing embryos require good exchange of water within the gravel in order to maintain satisfactory levels of dissolved oxygen, hence are highly sensitive to factors which limit this exchange, e.g. sedimentation;

(d) some coldwater species (e.g. brook trout) typically spawn in small streams which are less likely than large streams to be flushed of sediment and debris by high flows;

(e) most coldwater species spawn in the autumn; their eggs and developing embryos are thus exposed to possible environmental stresses for a longer period of time than are those of spring-spawning species.

As a result of these differences, habitat for coldwater species requires more protection from harmful effects of timber management operations than does that for other species. This distinction holds only for certain requirements such as shade, and, to some extent, input of nutrients and sediment.

Coolwater species (e.g. walleye) are somewhat less tolerant of high temperatures than are warmwater species (e.g. smallmouth bass). In general, however, the relative sensitivities of coolwater and warmwater species to the effects of timber management are unclear. For example, centrarchids (warmwater species) are typically nest builders and keep their eggs relatively clean by fanning them. Conversely, coolwater species deposit their eggs and then abandon them. Whether centrarchids are significantly less sensitive to sedimentation is unclear, however. Their ability to keep the nest free of silt and debris is limited. Furthermore, their eggs and fry may be exposed to the stress of sedimentation for a longer period of time than are those of coolwater species. In the absence of better information, it is assumed for present purposes that habitats of coolwater and warmwater species require similar levels of protection.

4.0 Potential Effects of Timber Management Operations on Fish Habitat

Requirements for fish habitat protection can best be addressed by considering how timber management operations can affect a watershed and the fish habitat within it. The following discussion of effects is limited to those of certain major operations, namely construction of access roads, harvesting, and mechanical site preparation.*

** The use of pesticides in timber management is not addressed in this document. Aerial spraying of herbicides and insecticides is to conform with existing policies and procedures, and the Ministry publication entitled "Aerial Spraying for Forest Management – an Operational Manual."*

4.1 Water Yield

The removal of forest cover results in an increase in the total water yield of the formerly forested area (Hibbert, 1967; Hetherington, 1987). The size of the increase is variable but is positively related to the amount of reduction in forest cover. Increased runoff is due primarily to the loss of both water consumption and evapotranspiration by the forest. Reduced infiltration capacity of the soil in areas of roads and skid trails may also result in rapid surface runoff.

Increased runoff can result in accelerated erosion, sedimentation and the addition of nutrients to watercourses. The significance of these effects for fish habitat is described in later sections.

The seasonal distribution of flows may also be changed by logging. Considerable variation in response among watersheds has been reported (Johnson, 1967). However, logging frequently results in higher peak flows (Henderson, 1978; Hetherington, 1987). Increased peak flows may cause scouring of bottom sediments, resulting in dislodgement of fish eggs or larvae and benthic invertebrates. High flows also accelerate bank cutting and stream widening with resultant loss of pools for fish.

Forest removal also generally increases low flows in

streams (Johnson, 1967; Hetherington, 1987). This may benefit fish and other aquatic organisms by providing more living space during the low flow seasons of late summer and mid-winter.

Effects of logging on water yield are normally greatest in the first few years after cutting. As revegetation occurs, these effects are reduced.

It is doubtful that the maintenance of standing timber on shorelands affects water yield significantly, unless the stand is so large as to reduce substantially the proportion of the watershed cut. Standing timber might be expected to moderate changes in seasonal distribution of flows by reducing surface runoff. Keeping roads and skid trails away from shoreland areas also reduces runoff.

4.2 Erosion and Sedimentation

4.2.1 Erosion. Timber management operations can contribute significantly to accelerated erosion. Roads are the most significant source of sediment (Freedman, 1982). Poor road drainage, unstable cuts and fills and improper stream crossings contribute to erosion (Rothwell, 1978). A study of low-use logging roads in northern Ontario indicated that significant erosion occurred on approximately six percent of the road surface, equivalent to one erosion problem every three miles (Mattice, 1977). Degree of slope has a major influence on the distance sediment travels from a road or other source (Trimble and Sartz, 1957).

Felling of trees into or near watercourses damages their banks, exposing soils to the erosional effects of rainfall, stream flow or wave action (Henderson, 1978). Trees felled into watercourses may also have a damming effect, resulting in bank cutting and consequent erosion.

Skidding across the forest floor disturbs the litter cover. Repeated travel over the same track exposes and compacts the mineral soil, reducing infiltration rates and increasing the potential for erosion. Skidding in or near watercourses greatly increases the risk that sediment will reach the water (Plamondon et al., 1982). Landings are also a potential source of sediment since the original ground vegetation is largely destroyed and soils may be highly compacted.

Mechanical site preparation disturbs the duff and may result in exposure of mineral soil. Consequently it is a potential cause of erosion until such time as sufficient revegetation has occurred to stabilize the soil.

4.2.2 Sedimentation. The harmful effects of suspended sediments (turbidity) on aquatic life include reduced photosynthetic activity due to reduction in light penetration, decreased levels of dissolved oxygen due to decomposition of organic sediments, damage to gill membranes, and reduced ability of fish to feed by sight.

The significance of such effects depends on the levels and nature of suspended sediments, as well as the duration of elevated levels. For example, mortality of adult fish as a result of gill damage occurs only after exposure of several days to levels of 200-300 ppm of suspended sediments (Phillips, 1971). The occurrence of such conditions as a result of logging is probably uncommon. However, lower levels of suspended sediments in combination with other stresses may reduce fish survival.

Of all the factors affecting aquatic life, sediment deposited on the stream or lake bed is the most damaging. Many fish species require clean substrate to spawn successfully. Even if spawning is successful, later sedimentation may reduce survival by reducing levels of dissolved oxygen within the gravel and may block the escape of emerging fry (Phillips, 1971; Lantz, 1971).

The accumulation of fine sediments in gravel areas reduces the diversity and abundance of benthic fish food organisms. Although certain prey species will inhabit a sand or silt bottom, they are not as available to fish as are species which live in gravel beds (Hynes, 1970; pp. 210, 373). Logging has been observed to increase the input of fine sediments to streams, resulting in reduced abundance of invertebrates (Culp and Davies, 1983).

Significant losses of fish production as a result of sedimentation from timber management operations have been documented (Hall and Lantz, 1969). Such losses are best prevented by the use of good management practices, particularly with respect to stream crossings and the planning and construction of roads.

The maintenance of standing timber on shorelands can be of significant value in reducing the effects of erosion and sedimentation. Maintaining this timber prevents the felling of trees into watercourses and discourages skidding in or across them. It also reduces surface runoff and traps sediment that originates from cut areas, roads or skid trails.

4.3 Logging Debris

The felling, slashing, skidding and yarding of timber near watercourses can result in debris entering the water.

Logging debris is organic in nature and decomposes slowly upon entering a watercourse. Decomposition of fine debris (leaves, twigs) results in an oxygen demand which may reduce dissolved oxygen concentrations. Reduced oxygen levels are particularly important on spawning areas and in the deep basins of coldwater lakes to which species such as lake trout are confined during periods of thermal stratification.

Slash may also block streamflow, reducing flow rates and adding to the problem of oxygen reduction. The

flow may be diverted and cause scouring of the bottom and banks, resulting in loss of benthos and increased sedimentation.

Logging debris may also block fish passage, preventing fish from reaching spawning areas or other habitats.

Limited amounts of large debris may benefit fish habitat provided that the debris is stable. For example, a fallen tree may offer cover for fish by providing shade and protection. However, fine debris is generally harmful and should be kept away from watercourses.

The maintenance of standing timber on shorelands can prevent logging debris from reaching watercourses by discouraging debris-producing activities near water and by acting as a barrier to the movement of debris.

4.4 Nutrient Input

Forest removal can significantly affect the nutrient balance of a watershed by reducing the uptake of nutrients by trees. Substantial increases in the input of several cations, nitrates, carbon and phosphorus to streams following deforestation have been demonstrated (Bormann et al., 1968; Hobbie and Likens, 1973). This situation has led to a concern for eutrophication and its effects on fish communities. However, largest losses of nutrients were obtained under unusual experimental conditions where regrowth of vegetation was prevented by the use of herbicides. Nutrient input resulting from conventional forest operations appears to be more limited (Henderson, 1978; Freedman, 1982; Nicolson et al., 1982). Revegetation reduces both the magnitude and duration of nutrient losses to water.

Inputs of phosphorus to watercourses are most relevant to the question of eutrophication since plant growth in most Ontario waters is phosphorus-limited. Phosphates adhere strongly to soil particles and thus are not easily leached, except from sandy soils. The potential for timber management operations to contribute phosphates to watercourses is therefore partly a function of the degree to which erosion and sedimentation occur. Inputs of sediment-bound phosphorus can contribute to eutrophication, but there is wide variation in the biological availability of such phosphorus (PLUARG, 1978; ECETA, n.d.).

Logging debris is a source of dissolved organic phosphorus through leaching and surface runoff. The biological availability of such phosphorus is not well known (ECETA, n.d.).

Addition of nutrients to a lake increases the production of plants and animals. Subsequent decomposition of this biological material may decrease the level of dissolved oxygen in deeper waters. In time, the fish species composition of the lake may also change.

The relatively high sensitivity of lake trout to nutrient enrichment is well known. In thermally stratified lakes, lake trout are generally confined to portions of the lake where temperatures are below 15°C and oxygen levels exceed 4 mg/L (Martin and Olver, 1976). Reduction of oxygen levels as a result of nutrient additions may thus reduce or eliminate habitat suitable for lake trout.

The maintenance of standing timber on shorelands can reduce the input of phosphorus to watercourses by reducing surface runoff and by trapping phosphorus-bearing sediment and logging debris.

4.5 Food Production

Food production within a stream can be markedly affected by removal of nearby timber. Many of the nutrients available to stream ecosystems in forested areas are derived from leaves and other detritus provided by nearby trees (Fisher and Likens, 1973). The invertebrate fauna are dependent on detritus for food and their numbers may be reduced if streambanks are logged (Culp and Davies, 1983). Many invertebrates are in turn food for fish. Fish also consume substantial numbers of terrestrial insects which fall into the stream from nearby vegetation. Removal of streamside vegetation during timber harvesting thus removes a major source of food.

Maintenance of streamside vegetation ensures a continued supply of food for stream organisms, including fish.

Because of their larger area, lakes are not as dependent on adjacent vegetation as a food source as are streams. Much of the energy available to the food chain of lakes is fixed by phytoplankton and macrophytes through photosynthesis. Hence the value of nearby timber for this purpose is not as great as in the case of streams.

4.6 Cover

Shoreline vegetation provides cover for fish, giving them protection against predators. Stream trout populations are adversely affected when undercut banks and overhanging vegetation are removed (White and Brynildson, 1967). Walleye are extremely sensitive to light (Ryder, 1977) and may also benefit from the shade provided by shoreline vegetation.

Maintenance of shoreline vegetation protects banks and provides cover for fish.

4.7 Temperature

Shoreline vegetation maintains lower water temperatures by shading. Shading may directly determine the survival or loss of trout populations, particularly in streams with borderline summer temperatures for trout. Removal of streamside vegetation results in higher summer temperatures and greater daily fluctuations in temperature, both of which may be detrimental to coldwater species (Brown and Krygier, 1970). Removal of vegetation may also bring about a reduction in dissolved oxygen since the solubility of oxygen decreases with increasing temperature.

On warm days, stream temperatures increase rapidly in unshaded reaches and decline, more slowly, when the water passes through shaded reaches (Barton and Taylor, 1981).

Small headwater streams are affected to the greatest extent by shade removal. At the same time, these streams often provide important spawning and nursery habitat for trout and thus require protection. Removal of vegetation from the shoreline of small headwater lakes may have a cumulative effect on water temperatures in downstream areas.

Maintenance of standing timber along streams and on shorelines of small headwater lakes can effectively moderate water temperatures by providing shade.

Where summer temperatures are not limiting for trout, timber cutting near streams may result in increased trout production if stream productivity is limited by available light (Murphy et al., 1981). Under these conditions, limited removal of the forest canopy may improve fish production.

5.0 Factors Influencing the Requirements for Modified Timber Management

5.1 Location of Areas of Operations

The risk of damage to fish habitat as a result of timber management operations is influenced greatly by the nature of operations on adjacent shorelands. As these shorelands provide the interface between land and water, they are critical to the protection of fish habitat. Nonshoreland areas are less important to habitat protection and, consequently, normal operations may generally be carried out in such areas.

As described in the Timber Management Planning Manual for Crown Lands in Ontario, the Ministry's planning process for integrating other resource values in timber management requires the identification of "areas of concern". These are areas where other resource values could be affected by timber operations and where modifications may be required. For purposes of fish habitat protection, such areas are basically areas which have been selected for operations and which are adjacent to fish habitats requiring protection. Areas of concern are discussed further in Section 6.0.

5.2 Habitat Protection Requirements

Requirements for modified timber management are determined in part by habitat protection requirements. As discussed in Section 3.0, some habitats require a particularly high level of protection. Also, fish species vary in their sensitivity to potential effects of timber management. These factors affect protection requirements and, in turn, the need for modified management.

Habitat protection requirements in a given situation are influenced by local fisheries management objectives as expressed in documents such as District Land Use Guidelines and District Fisheries Management Plans. These documents identify what benefits are to be achieved from the local fisheries resource. This in turn establishes the need to protect habitats on which the resource depends.

Not all aquatic habitats are of value to fish. Habitats not capable of supporting fish, and those for which rehabilitation is not presently feasible, may not require protection.

5.2.1 Critical Fish Habitats. Some fish habitats are critical to the maintenance of fish populations and require a high level of protection. These include headwater areas (e.g. springs), spawning, nursery and migration areas, and wetlands. The need to protect these habitats may require significant modifications in timber management on adjacent shorelands.

Protection of critical fish habitats requires taking particular care to ensure that the natural functions of the adjacent land environment are maintained. Any disturbance on shorelands which is likely to have an adverse impact on adjacent critical fish habitat should be avoided.

Migration areas do not generally require the same level of protection as do other critical habitats. Provided that banks are protected, debris is kept away from watercourses, and proper stream crossings are installed, fish migration is not likely to be affected by timber management operations. Guidance on the installation of stream crossings is contained in the Ministry's Environmental Guidelines for the Construction of Access Roads (in preparation).

5.2.2 Lake Trout Lakes, Self-Sustaining Brook Trout Lakes, Aurora Trout Lakes. Lake trout are highly sensitive to environmental stress, including the kinds of effects which may result from timber management on shorelands. As for critical habitats, any disturbance which is likely to have an adverse impact on lake trout lakes should be avoided.

The same protection is required for self-sustaining brook trout lakes and aurora trout lakes. These species spawn in shallow seepage areas which may be scattered around the shore. Since these areas are not often evident, the entire shoreline requires a high level of protection.

5.2.3 Other Fish Habitats. Habitat protection requirements are related to the temperature tolerance of fish species. As discussed previously (Section 3.0), habitat for coldwater species requires somewhat more protection than for other species. This is particularly true with respect to requirements for shade, which may necessitate the maintenance of standing timber on shorelands.

Some intermittent streams provide valuable spawning habitat during certain times of the year (Erman and Hawthorne, 1976). Such streams require as much protection as do permanent streams.

Some habitats may not require the same level of protection as do others. In the case of coolwater and warmwater habitats, in particular, a greater degree of disturbance on the shoreland may be acceptable

provided that certain precautions are taken. Consequently, the required modifications to timber management may be less significant than for coldwater habitats.

5.3 Composition of Shoreland Vegetation

The maintenance of bank stability is dependent more on the abundance of shoreland vegetation than on the type of vegetation present. Of most importance is a thick root system holding the soil together as well as sufficient stems and leaves to protect the soil surface from erosion due to rainfall and runoff. The presence of standing timber is not necessarily required for bank stability, provided sufficient vegetation of other kinds is present.

Similarly, many types of vegetation including grasses, shrubs and trees are effective in providing a barrier to the movement of sediment and logging debris.

The presence of deciduous vegetation near streams is of importance to food production, since leaves are an important source of nutrients. Alders, for example, are nitrogen-fixing plants and their leaves are particularly high in nitrogen.

Where shading is required, the height of shoreline vegetation is important. A few tall spruce near the water's edge provides more shade than does low growth of willows and alders (Cormack, 1949). However, standing timber is not always required for shade, particularly on small streams where a canopy of understory vegetation can be equally effective.

In summary, the protection of fish habitat depends more on the abundance of shoreland vegetation than on the type of vegetation present. If sufficient vegetation of other types is available, timber harvesting need not necessarily be modified to leave standing timber on shorelands. The maintenance of some hardwoods near streams may be desirable as a food source and some standing timber may be required for shade, particularly on large streams.

5.4 Width of Shoreland Vegetation

Within limits, the risk of damage to fish habitat from timber management operations decreases as the width of intervening vegetation increases. However, the width required for adequate protection depends on many factors. These include the nature of local fish habitats, local site conditions and habitat protection objectives.

The maintenance of vegetation (including timber stands) adjacent to fish habitat provides important protection from erosion and sedimentation. The width of vegetation required for adequate protection depends on factors which influence the amount of sediment produced and transported, including climate, vegetation, soils and topography.

The susceptibility of a soil to water erosion is related to its texture (UDPIC, 1983). Coarse textured (sandy) soils are generally of low erodibility because of their high infiltration capacity and the frictional resistance of large particles. Fine textured (clay) soils also tend to exhibit low erodibility because of their high cohesive strength. Conversely, medium textured (loam) soils tend to be highly erodible.

The moisture content of a soil also influences its erodibility. Poorly drained soils are particularly susceptible to erosion because of their low infiltration capacity.

Slope is an important factor influencing erosion and sedimentation. The following relationship between slope and width of standing timber necessary to filter out sediment was developed in New Hampshire (after Trimble and Sartz, 1957).

Slope %	Width of Standing Timber	
	Municipal Watershed	General Situation
0	15 m	8 m
10	27 m	14 m
20	40 m	20 m
30	52 m	26 m
40	64 m	32 m
50	76 m	38 m
60	88 m	44 m

The above widths will not always prevent sediment from reaching a watercourse in the general situation. Widths specified for municipal watersheds include a safety factor and are designed to prevent any input of sediment.

The maintenance of sufficient vegetation to prevent sedimentation of watercourses should also help to reduce phosphorus inputs, since phosphates are largely adsorbed to soil particles. Similarly, such vegetation should also serve to keep out logging debris.

To provide cover and food for fish, shoreline vegetation must be maintained. Such vegetation includes trees from which leaves and insects can fall into the water. Few trees farther than 15 m from a watercourse are major contributors of food (van Groenewoud, 1977).

Protection of aquatic invertebrates as a food source for fish requires a strip of vegetation approximately 30 m in width. Studies of the effectiveness of buffer strips in protecting stream invertebrate communities indicate that strips less than 30 m provide only partial protection (Newbold et al., 1980; Culp and Davies, 1983).

Where protection from excess temperatures is required, shoreland vegetation should be sufficient to provide effective shade. The percentage of sunlight reaching a stream declines rapidly with distance from the streambank, up to a width of 7.5 m (van Groenewoud, 1977). Zones beyond 15 m in width provide very little additional protection, in either hardwood or softwood stands.

Effective protection of fish habitat requires that adjacent trees be protected from blowdown. Where the probability of blowdown is high, the width of standing

timber must usually be greater than when the probability is low, in order to provide wind resistance (cf. Section 5.6).

5.5 Continuity of Standing Timber

A continuous stand of timber or other vegetation on shorelands offers most protection to fish habitat. Where a high degree of protection is required, a continuous stand of timber should be maintained wherever possible. In general, critical fish habitats should be protected by maintaining continuous stands on adjacent shorelands. Because of the high sensitivity of lake trout to environmental stress, lake trout lakes require the maintenance of continuous timber stands along the entire shoreline. The same protection is required for self-sustaining brook trout lakes and aurora trout lakes.

In some cases a continuous stand of timber may not be necessary. Cutting close to the shoreline or near streams may be acceptable in areas apart from critical habitats, provided that care is taken to avoid damaging banks, to keep debris away from watercourses, and to avoid the occurrence of erosion. For example, limited cutting near a warmwater lake may be acceptable in some situations (cf. Section 7.3.3).

Effective protection of critical stream habitats requires that upstream reaches also be protected. Where possible, a continuous stand of timber should be maintained upstream at least to the first permanent water basin or bog. This provides an opportunity for sediment and debris to settle out.

Where shade is required on streams for coldwater fish, a continuous timber stand on both banks is desirable. Temperatures increase rapidly in unshaded reaches, then decline more slowly when the water is shaded once again. Maximum protection from heating requires that the stand extend the full length of the stream and also protect feeder streams and springs.

5.6 Blowdown

Narrow strips of timber left standing after logging operations are susceptible to blowdown. The occurrence of blowdown depends on several factors including tree species and age, soil conditions, topography, prevailing winds and width of the stand. Generally, trees growing on deep, dry soils have better developed root systems than do those on moist, shallow soils and hence are more wind-firm.

Extensive blowdown may damage fish habitat due to accompanying bank erosion and input of debris to the watercourse. Some of the benefits (food, shade) for which the stand may have been intended are no longer provided. Hence, an effort should be made to prevent blowdown on shorelands by maintaining stands of a size and configuration conducive to providing wind resistance.

Although the benefits of a stand are largely lost if it blows down, fallen trees may continue to provide protection from sedimentation since they can effectively trap sediment (Trimble and Sartz, 1957). In some cases, trees which have fallen into the water can provide valuable cover for fish.

Susceptibility of a stand to blowdown decreases as the width of the stand increases. However, it is not possible to specify a width which will insure that no blowdown occurs. Requirements to prevent blowdown are site-specific and the width of standing timber maintained must be prescribed accordingly.

6.0 Areas of Concern

6.1 Identification of Areas of Concern

As discussed in Section 5.1, the Ministry's timber management planning process requires the identification of areas of concern with respect to other resource values. For purposes of protecting fish habitat and water quality, the extent to which areas of concern can be identified at any given time depends on the level of detail of timber management planning. At the level of the twenty-year planning period, only those areas eligible for operations are identified. Consequently, areas of concern can be identified only in a preliminary way. At this stage it may be possible only to identify all shorelands in areas eligible for operations as areas of concern.

It is at the five-year level of planning where specific areas of concern can be identified. At this time the areas selected for operations are identified and habitat information is more readily available. Wherever water quality or fish habitat must be protected, all portions of the shoreland selected for timber operations should be identified as areas of concern. Thus several areas of concern may be identified on the shoreland of a single lake or stream. The associated values requiring protection should also be described.

For each of the identified areas of concern, a decision will be made as to whether timber management operations may occur within the area and if so, what modifications are required to protect fish habitat. Outside areas of concern, normal timber management operations will be carried out.

6.2 Size of Areas of Concern

From the discussion in Section 5.4, it is apparent that for purposes of fish habitat protection, no more than approximately 90 m of undisturbed vegetation need usually be maintained on shorelands. On gentle slopes (<15%) as little as 30 m of vegetation can provide effective protection. Therefore, the width of areas of concern required to protect fish habitat generally varies from 30 to 90 m, depending on slope (see also Section 7.2). In some locations, however, the width of these areas may have to be greater to reduce the risk of blowdown.

It should be noted that areas of concern identified for the protection of fish habitat may not be sufficiently large to protect other resource values.

Within areas of concern, habitat protection require-

ments may vary significantly. In particular, the presence of critical fish habitats may require greater modifications in timber management in adjacent areas than in other portions of the area of concern. Such requirements are considered in developing specific operational prescriptions for timber management.

7.0 Rationale for Provincial Guidelines

7.1 Introduction

The Timber Management Guidelines for the Protection of Fish Habitat are designed to provide a broad, consistent approach to protecting fish habitat and water quality that is applicable throughout the province. However, because of the many local factors affecting requirements for protection, it is not possible to specify guidelines that will be adequate in every case. Local managers should therefore use their discretion in adapting the guidelines to the needs of site-specific situations. Any departures from the guidelines must, however, be consistent with the objective of protecting fish habitat and water quality.

The guidelines outline modifications to timber management which are generally required on shorelands for the protection of specific fish habitats. Certain harvesting options are presented. The choice of option will be determined by many factors including fisheries management objectives, site conditions, and the feasibility of specific options in local situations.

In the Boreal Forest Region, certain harvesting options are generally not as feasible as in the Great Lakes-St. Lawrence Forest Region. The normal harvesting system used in the Boreal Forest is clear cutting. In some situations it may not be feasible to restrict harvesting within an area of concern in a manner consistent with the guidelines. In such cases there is no option but to exclude timber management operations from the area of concern. Thus the area of concern becomes a reserve.

As discussed in Section 5.2, effective protection of fish habitat requires that harmful disturbance on adjacent shorelands be avoided. The maintenance of shoreland vegetation (including timber stands) buffers the effects of disturbance elsewhere, thereby protecting fish habitat.

In areas selected for timber management operations, the need to avoid harmful disturbance may require major management modifications. Where no amount of disturbance in the area of concern is judged acceptable, operations must be excluded entirely. Where some disturbance within the area of concern is acceptable, it may be possible to modify operations so as to ensure protection of fish habitat. All or part of the area of concern thus becomes an area of modified operations.

7.2 Width of Areas of Concern

The widths of areas of concern specified in the guidelines are adapted from the recommendations of Trimble and Sartz (1957) for protecting watercourses from any input of sediment. These widths apply to each bank of a stream and vary with slope.

To simplify the determination of appropriate width of area of concern, widths are specified for four ranges of slope where slope is expressed in percent and its approximate equivalent in degrees.

To protect fish habitat most effectively, the width of area of concern specified for each range of slope approximates the maximum value recommended by Trimble and Sartz for slopes at the upper end of the range. Thus the narrowest area of concern specified is 30 m. A strip of standing timber or other vegetation this wide normally provides effective protection on slopes up to 15%. This width also helps to protect standing timber from blowdown, although larger stands may be required for this purpose.

It should be noted that the widths of areas of concern specified in the guidelines are for general use and should be applied with some flexibility. Where better information is available on a local basis, widths may be modified in a manner consistent with the protection of fish habitat.

7.3 Operations within Areas of Concern

The following discussion focusses on the acceptability of certain timber management operations within areas of concern, with respect to protecting fish habitat. Conditions under which these operations may be acceptable are described and some desirable modifications are outlined.

7.3.1 Roads. Road construction causes major disturbance of the environment and generally poses a higher risk of damage to fish habitat and water quality than do other timber management operations. Therefore, roads should not be located within areas of concern. In some cases, exceptions may be considered where the needs of timber management clearly require that a road enter an area of concern, for example to cross a stream. In such cases, road construction within the area of concern should occur only where it can be demonstrated that road design, construction, use and maintenance will ensure protection of fish habitat and water quality.

7.3.2 Landings. Like roads, landings also create significant disturbance and should not be located within areas of concern.

7.3.3 Harvesting. Timber harvesting is often incompatible with the objective of avoiding harmful disturbance on shorelands. However, in some cases it may be acceptable to carry out limited harvesting within areas of concern, permitting the harvesting of additional timber. Such harvesting may prevent deterioration of the forest within the area of concern, thereby maintaining the benefits it provides.

If done with extreme care, the removal of single trees or small groups of trees (selection cutting) may cause little disturbance. Where selection cutting is

carried out near coldwater streams, it is essential that shade be maintained on both sides of the stream and throughout its length. Additional disturbance should be avoided by deferring any further cutting until the original cut areas have become stabilized through revegetation.

In general, the use of light equipment poses less risk of erosion than does the use of heavy equipment. Harvesting on frozen soils reduces the risk of erosion while harvesting on wet soils increases the risk.

In some situations it may be possible to use other, generally more disruptive, harvesting systems in areas of concern. This applies particularly to coolwater (e.g. walleye) and warmwater (e.g. bass) habitats where a greater degree of disturbance on the shoreland may be acceptable. Extensive clear cutting is not compatible with habitat protection. However, if done with care, shelterwood cutting or some form of limited clear cutting (e.g. strip or block cuts) may be acceptable in some areas of concern. Such cutting should not occur in areas adjacent to habitats requiring a high degree of protection (e.g. critical fish habitats) or in areas upstream of critical habitats. Also, cutting should not occur between the shoreline and nearby roads since shoreland vegetation must be maintained to protect fish habitat from sedimentation.

Where shelterwood or clear cutting is carried out in areas of concern, it may be necessary to restrict the size of cuts to avoid significant impacts. No more than 50% of the shoreline of lakes or 50% of the length of streams should be cut by these methods and any cutting should occur, where feasible, in noncontiguous blocks or strips. It is recognized that such cutting may not be feasible near small lakes.

Where shelterwood or clear cutting is carried out, harvesting should not occur in areas where there is a risk of significant erosion. Methods, equipment and timing should be chosen so as to ensure protection of fish habitat.

7.3.4 Mechanical Site Preparation. Mechanical site preparation disturbs the duff and may expose mineral soil. Consequently its use in shoreland areas poses a risk of erosion and sedimentation. However, in some situations it may be possible to carry out this operation without harming fish habitat.

The degree of disturbance caused by mechanical site preparation varies with site conditions as well as with equipment and methods employed. Equipment should be selected so as to expose the minimum amount of mineral soil consistent with successful regeneration. The risk of sedimentation is also reduced by orienting furrows at right angles to the slope.

7.4 Definitions

Some wetlands provide valuable spawning habitat as well as nursery areas for certain species of fish. For purposes of the guidelines, wetlands are defined as areas of shallow water characterized by the presence of aquatic vegetation and which provide spawning or nursery habitat for fish.

Habitat protection requirements are related to the temperature tolerance of fish species. For purposes of the guidelines, coldwater streams are distinguished from coolwater and warmwater streams. Coldwater streams are defined here as those capable of supporting salmonid species, while coolwater streams are those capable of supporting coolwater fish such as walleye and northern pike. Similarly, warmwater streams are those capable of supporting warmwater species such as smallmouth bass.

Because of their sensitivity to environmental stress, lake trout, brook trout and aurora trout require the highest level of protection. Consequently, lakes capable of supporting these species are distinguished from those of other species.

Some intermittent streams provide valuable spawning habitat during certain times of the year. In the guidelines, references to streams include permanent streams as well as those intermittent streams which provide spawning habitat for fish.

Some tributaries to coldwater lakes may not be inhabited by salmonids yet are critical sources of water to these lakes. Such tributaries should receive the same protection as do streams inhabited by salmonids. In the guidelines, references to coldwater streams include these tributaries.

Fisheries management objectives for specific lakes and streams are stated in District Fisheries Management Plans. This enables specific waters to be categorized for purposes of the guidelines (e.g. lake trout lake). Decisions made in developing the District Fisheries Management Plans thus direct the application and implementation of the guidelines.

REFERENCES

REFERENCES

Barton, D.R., and W.B. Taylor. 1981. The relationship between riparian buffer strips and trout habitat in southern Ontario streams. University of Waterloo. Project No. 912-13.

Bormann, F.H., G.E. Likens, D.W. Fisher and R.S. Pierce. 1968. Nutrient loss accelerated by clear-cutting of a forest ecosystem. Science 159:882-884.

Brown, G.W., and J.T. Krygier. 1970. Effects of clear-cutting on stream temperature. Water Resources Res. 6(4):1133-1139.

Cormack, R.G.H. 1949. A study of trout streamside cover in logged-over and undisturbed virgin spruce woods. Can. J. Research 27 (C):78-95.

Culp, J.M., and R.W. Davies. 1983. An assessment of the effects of streambank clear-cutting on macroinvertebrate communities in a managed watershed. Can. Tech. Rept. Fish. Aquat. Sci. No. 1208, Fisheries and Oceans Canada.

ECETA. n.d. Biological availability of phosphorus. Expert Committee on Engineering and Technological Aspects of Great Lakes Water Quality. Report to Great Lakes Science Advisory Board.

Erman, D.C., and V.M. Hawthorne. 1976. The quantitative importance of an intermittent stream in the spawning of rainbow trout. Trans. Amer. Fish. Soc. 105(6): 675-681.

Fisher, S.G., and G.E. Likens. 1973. Energy flow in Bear Brook, New Hampshire: an integrative approach to stream ecosystem metabolism. Ecol. Monogr. 43(4):421-439.

Freedman, B. 1982. An overview of the environmental impacts of forestry, with particular reference to the Atlantic provinces. I.R.E.S. Research Rept. 82-02, Inst. for Resource and Environ. Studies, Dalhousie University, Halifax, N.S.

Groenewoud, H. van. 1977. Interim recommendation for the use of buffer strips for the protection of small streams in the Maritimes. Can. For. Serv., Dept. Fish. and Environ. Fredericton, N.B. Info. Rept. M-X-74.

Hall, J.D., and R.L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. In Northcote, T.G. (ed.). Symposium on Salmon and Trout in Streams. pp. 355-375. H.R. MacMillan Lectures in Fisheries. University of British Columbia.

Henderson, J.M. 1978. The effects of forest operations on the water resources of the Shubenacadie – Stewiacke River Basin. Shubenacadie-Stewiacke River Basin Board, Tech. Rept. No. 11.

Hetherington, E.D. 1987. The importance of forests in the hydrological regime. In Healey, M.C., and R.R. Wallace (ed.). Canadian Aquatic Resources. pp. 179-211. Can. Bull. Fish. Aquat. Sci. 215.

Hibbert, A.R. 1967. Forest treatment effects on water yield. In Sopper, W.E., and H.W. Lull (ed.). Forest Hydrology. pp. 527-543. Pergamon Press.

Hobbie, J.E., and G.E. Likens. 1973. The output of phosphorus, dissolved organic carbon, and fine particulate carbon from Hubbard Brook watersheds. Limnol. Oceanogr. 18:734-742.

Hynes, H.B.N. 1970. The ecology of running waters. University of Toronto Press.

Johnson, E.A. 1967. Effects of multiple use on peak flows and low flows. In Sopper, W.E., and H.W. Lull (ed.). Forest Hydrology. pp. 545-550. Pergamon Press.

Lantz, R.L. 1971. Guidelines for stream protection in logging operations. Oregon State Game Commission, Portland.

Martin, N.V., and C.H. Olver. 1976. The distribution and characteristics of Ontario lake trout lakes. Research Report No. 97, Fish and Wildlife Research Branch, Ont. Ministry of Natural Resources.

Mattice, C.R. 1977. Forest road erosion in northern Ontario: a preliminary analysis. Can. For. Serv., Dept. Fish. and Environ. Rept. O-X-254.

Murphy, M.L., C.P. Hawkins, and N.H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. Trans. Amer. Fish. Soc. 110(4):469-478.

Newbold, J.D., D.C. Erman, and K.B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aquat. Sci. 37:1076-1085.

Nicolson, J.A., N.W. Foster and I.K. Morrison. 1982. Forest harvesting effects on water quality and nutrient status in the Boreal Forest. Can. Hydrol. Symp. 82, National Research Council of Canada, June 14-15, 1982, Fredericton, N.B.

Phillips, R.W. 1971. Effects of sediment on the gravel environment and fish production. In Krygier, J.T., and J.D. Hall (ed.). Proc. Symposium on Forest Land Uses and Stream Environment. Oregon State University, Corvallis.

Plamondon, A.P., A. Gonzalez, and Y. Thomassin. 1982. Effects of logging on water quality: comparison between two Quebec sites. Can. Hydrol. Symp. 82, National Research Council of Canada, June 14-15, 1982, Fredericton, N.B.

PLUARG. 1978. Environmental management strategy for the Great Lakes system. Int. Reference Group on Great Lakes Pollution from Land Use Activities, final report to IJC.

Rothwell, R.L. 1978. Watershed management guidelines for logging and road construction in Alberta. Can. For. Serv., Dept. Fish. and Environ. Info. Rept. NOR-X-208.

Ryder, R.A. 1977. Effects of ambient light variations on behaviour of yearling, subadult, and adult walleyes (Stizostedion vitreum). J. Fish. Res. Board Can. 34:1481-1491.

SPOF. 1976. Federal-Provincial strategic planning for Ontario fisheries – preliminary analysis of goals and issues. First report, second edition. Federal-Provincial Working Group on Strategic Planning for Ontario Fisheries.

Trimble, G.R., and R.S. Sartz. 1957. How far from a stream should a logging road be located? J. Forestry 55(5):339-341.

UDPIC. 1983. Guidelines on erosion and sediment control for urban construction sites. Urban Drainage Policy Implementation Committee No. 5, Ontario.

White, R.J., and 0. M. Brynildson. 1967. Guidelines for management of trout stream habitat in Wisconsin. Wis. Dept. of Natural Resources, Tech. Bull. No. 39, Madison.